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(54) Method and apparatus for validating coins

(57) Coins are validated by causing them to produce an impact, sampling a time-varying signal having characteristics dependent on the impact and combining the samples in a weighted manner to produce an output that is representative of the shape of the signal which is in turn influenced by coin hardness.

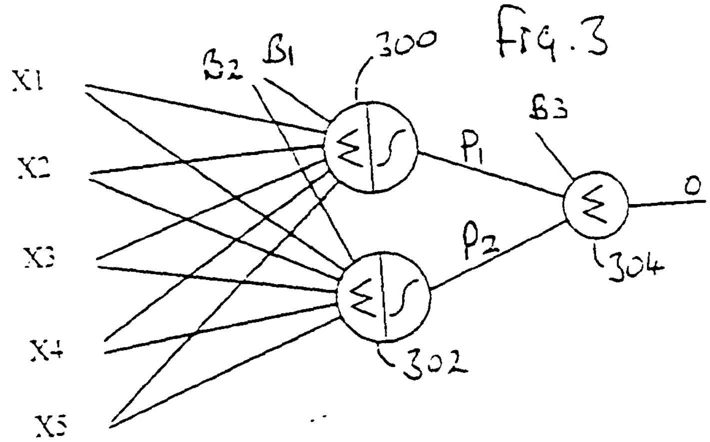

Fig. 3

Description

[0001] This invention relates to a method and an apparatus for validating coins.

[0002] It is known that a substantial number of counterfeit coins have electrical and magnetic properties which resemble those of genuine coins, so that coin validators erroneously indicate them to be genuine, but have different mechanical properties. In particular, many counterfeit coins are softer than the genuine coins which they otherwise resemble. It has been proposed to distinguish between such counterfeit coins and genuine coins by detecting the vibrations caused after an impact between the tested item and an element of the coin validator. Piezoelectric elements have been used for sensing the vibration. See for example GB-A-2 236 609 and EP-A-543 212.

[0003] It would be desirable to provide a more reliable method for testing for such counterfeits, thereby providing better discrimination, and an apparatus which employs such a method.

[0004] Various aspects of the invention are set out in the accompanying claims.

[0005] According to another aspect, a coin validator determines the shape of at least the initial part of a vibration caused by an impact of the coin being tested, the coin validator then taking the determined shape into account in producing a signal indicating whether or not the tested coin is genuine. The validator can be arranged to indicate that the coin is not genuine unless the shape is determined to be appropriate. Alternatively, the closeness of the determined shape to an appropriate shape can be used as one of a number of factors taken into account in determining whether the coin is genuine, and possibly the coin denomination.

[0006] Preferably, the vibration produced by the coin impact is sensed by a piezoelectric element, and the output signal is processed to determine the shape of the initial part of the vibration. It has been found that this shape is characteristic of material properties of the coin being tested, and particularly the hardness. Depending upon the structure of the coin validator and the manner in which the impact is produced and sensed, the later part of the signal may be less representative of the coin properties and therefore it is preferable to disregard this part of the signal. For example, in particular embodiments, it has been found that although the initial part of the vibration contains information indicative of the coin hardness, the later parts of the vibration are dominated by the mechanical characteristics of the validator. Preferably, the shape of the vibration waveform is determined on the basis of the vibration during the first millisecond after the impact, and more preferably during the first quarter of a millisecond.

[0007] The data used to determine the shape of the vibration waveform can be derived in a number of ways. In the preferred embodiment, the waveform amplitude is sampled at predetermined intervals. Preferably, the sampling commences when the amplitude reaches a predetermined threshold level

[0008] In an altemative embodiment, the waveform is monitored to determine the times at which predetermined amplitudes are reached. This, however, is less preferable because it has been found that the range of amplitudes varies substantially from impact to impact, so that allowing for the largest range of amplitudes would result in a loss of resolution.

[0009] In a further alternative embodiment, the vibration waveform is processed to determine the time and amplitude at which certain events occur, for example the times and amplitudes of the peaks and troughs in the vibration waveform. However, this could also suffer from dynamic range problems, and requires additional processing.

[0010] Various techniques can be used to determine the shape of the vibration waveform using the derived data samples. In the preferred embodiment, the samples are weighted and summed, and preferably applied to a non-linear function. This could be performed a number of times, with the outputs of the non-linear functions also being combined in a weighted manner. To derive the weighting factors, a neural network can be trained in a per se known manner, e.g. using back propagation.

[0011] While neural networks provide a rapid method of generating an algorithm to process the data, algorithms could obviously be developed by other methods to provide discrimination between numerical representations of the waveforms. Analysis would lead to an understanding of the relationships between the waveform and the known form of the coin giving rise to the signal. The waveform data could be analysed to discover deeper interrelationships. Non linearities might be accommodated by use of power laws, logarithms, trigonometrical or other functions. Regression techniques could be employed, for example, with polynomials to develop a model which ultimately discriminates the waveforms. These approaches would work, but use of a neural network is preferred because it leads to a fast and sufficiently effective result which is simple to incorporate in a product.

[0012] An arrangement embodying the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 schematically shows a coin validator in accordance with the invention;
Figure 2 is a diagram illustrating the sampling of a vibration waveform; and
Figure 3 is a diagram illustrating the manner in which the data samples representing the waveform are processed.

[0013] Referring to Figure 1, the validator 2 comprises a test structure 4. This structure comprises a deck (not shown) and a lid 6 which is hingedly mounted to the deck such that the inner sides of the deck and lid are in prox-

imity to and face each other. Figure 1 shows the test structure 4 as though viewed from the outer side of the lid. The inner side of the lid is moulded so as to form, with the deck, a narrow passageway for coins to travel edge first in the direction of arrows A.

[0014] The moulded inner surface of the lid 6 includes a ramp 8 along which the coins roll as they are being tested. At the upper end of the ramp 8 is an energy-absorbing element 10 positioned so that coins received for testing fall on to it. The element 10 is preferably made of material which is harder than any of the coins intended to be tested, and serves to remove a large amount of kinetic energy from the coin as the coin hits the element. The energy-absorbing element may be structured and mounted as shown in EP-A-466 791.

[0015] A wall 12 is formed on the outer side of the lid 6, and a piezoelectric element 14 is mounted on this wall. The vibrations caused by the coin impacting the energy-absorbing element 10 pass through the test structure 4, and in particular are carried by the lid 6 and the wall 12 to the piezoelectric element 14, which generates a signal on an output line 16.

[0016] As the coin rolls down the ramp 8, it passes between three coils 18 mounted on the lid, and a corresponding set of coils (not shown) of similar configuration and position mounted on the deck, forming three pairs of coils, the coils of each pair facing each other across the coin passageway. The coin is subjected to electromagnetic testing using these coils 18.

[0017] The coils 18 are connected via lines 20 to an interface circuit 22, which also receives signals from the piezoelectric element 14 via output line 16.

[0018] The interface circuit 22 comprises oscillators for driving the electromagnetic coils 18, circuits for appropriately filtering and shaping the signals from lines 16 and 20 and a multiplexing circuit for delivering any one of the signals from the piezoelectric element 14 and the pairs of coils 18 to an analog-to-digital converter 24.

[0019] A control circuit 26, including a microprocessor, has an output line 28 connected to the analog-to-digital converter 24, and is able to send pulses over the output line 28 in order to cause the analog-to-digital converter 24 to take a sample of its input signal and provide the corresponding digital output value on a data bus 30.

[0020] In this way, the control circuit 26 can obtain digital samples from the test structure 4, and in particular from the piezoelectric element 14 and the coils 18, and can process these digital values in order to determine whether a received test item is a genuine coin or not. If the coin is not determined to be genuine, an accept/reject gate 32 will remain closed, so that the coin will be sent along the direction B to a reject path. However, if the coin is determined to be genuine, the control circuit 26 supplies an accept pulse on line 34 which causes the gate 32 to open so that the accepted coin will fall in the direction of arrow C to a coin separator (not shown), which separates coins of different denominations into different paths and directs them to respective coin stores (not shown).

[0021] In this embodiment a single analog-to-digital converter 24 is used in a time-sharing manner for processing the signals from the coils 18 and from the piezoelectric element 14. However, a plurality of converters could be provided if desired.

[0022] The output from the piezoelectric element 14 is processed in the manner described below in order to determine whether the received test item is of relatively soft material, indicating that it is a counterfeit. If so, the control circuits 26 will reject the test item irrespective of the signals provided by the coils 18.

[0023] Referring to Figure 2, this shows an exemplary vibration waveform produced by the piezoelectric element 14 on output line 16 following the impact of the test item with the energy-absorbing element 10. The control circuit 26 repeatedly checks the output of the analog-to-digital converter until the amplitude of the signal on line 16 reaches a predetermined threshold T (of, for example, 200 millivolts). (If desired, a hardware comparator can be provided for this purpose, the comparator providing a signal to the control circuit 26 when the threshold is reached.) A timer is then started. Subsequently, the timer causes the control circuit 26 to take five samples X1 to X5 of the output signal at 35 microsecond intervals.

[0024] Referring to Figure 3, these data samples are then processed as illustrated schematically here. A first process, schematically illustrated by the neuron 300, takes all five values and multiplies each one by a respective predetermined weight and then sums them with a bias value B1. The sum is then applied to a non-linear function, for example a sigmoid function or a hyperbolic tangent function, to provide an output value P1.

[0025] A second process illustrated by neuron 302 performs a similar operation, except using different weights and a different bias value B2, to produce an output value P2.

[0026] A third process, illustrated by a summing junction 304, multiplies each of the output values P1 and P2 by a respective weight and adds these to a bias value B3 to produce an output value O.

[0027] This output value is dependent on the shape of the initial part of the waveform shown in Figure 2, which in turn is influenced by the hardness of the test item. The weights and the bias values are so chosen that the control circuit 26 can determine whether the test item is relatively soft, indicating a counterfeit coin, by determining whether or not the output value O exceeds a predetermined threshold. Accordingly, the output value O is compared with this threshold in order to produce a yes/no output.

[0028] In an alternative embodiment, the output value O is compared to a range of values, and the processor determines that the test item is a counterfeit in dependence upon whether or not the value lies within the range. This would for example be useful if there are counterfeit coins which have a hardness greater than that of genu-

ine coins.

[0029] Because the piezoelectric element 14 is situated upstream of the coils 18, the processing of the output signal from the element can occur before the output signals from the coils need to be processed. If the output of the piezoelectric element indicates that a counterfeit coin has been received, the processing of the output signals from the coils can be omitted.

[0030] In an alternative embodiment, the signal from the piezoelectric element 14 is used (preferably together with the signals from the coils 18) to determine the denomination of a genuine coin. Thus, the validator can be arranged to store acceptance criteria for each of the denominations it is intended to validate. For each denomination, there may be stored criteria determining the type of signals expected to be received from the coils when testing a coin of that denomination. In addition, in accordance with this embodiment, there can be acceptance criteria for the value O, which criteria would vary according to denomination. Thus, the value O could be compared with a plurality of ranges, each associated with a different denomination. Also or alternatively, if desired, in order to determine whether the tested item corresponds to any of a number of different coin denominations, it is possible to use different sets of weights and bias values, each set being used to determine whether the item corresponds to a respective denomination.

[0031] Instead of using the output value O to indicate whether or not a particular coin has been tested, it could be used as one of a number of discriminants which are considered in combination to evaluate the tested item, for example using the techniques of EP-A-0 496 754.

[0032] The weights and the bias values used in the processing illustrated in Figure 3 can be derived using an iterative training process. Conventional neural network techniques, such as back propagation, can be used. Samples of genuine and counterfeit coins would be repeatedly tested, while the weights and bias values are modified to enhance the discrimination between them, and, if desired, between coins of different denominations. This operation can be performed after assembly of the coin validator using a training procedure on each individual validator. Preferably, however, the training procedure uses data from a plurality of reference validators, whereby the derived weights and biases will not be validator-specific, so that common values can thereafter be used in production of new validators and it is not necessary to determine individual weights and biases for each production validator. The output values O may however be different for different validators, in which case individual calibration of the validators may be performed by insertion of genuine coins to derive suitable acceptance criteria for the values O.

[0033] The processing illustrated in Figure 3 can be varied considerably. The neurons 300 and 302 represent a hidden layer. If desired there could be additional neurons in this layer, or one or more additional layers, or the layer can be omitted. The non-linear functions performed by these neurons can be omitted, or a further non-linear function can be added to the neuron 304. Instead of combining the weighted samples before applying the sum to a non-linear function, non-linear functions can be applied to the samples prior to combining them. Instead of using simple weighting and summing operations, other techniques can be used for processing and combining the individual values. It is, however, preferable for there to be at least three values, and preferably five or more values, representing different amplitude/time points on the waveform, to provide at least an approximate indication of waveform shape. In the embodiment described above there are effectively six values, representing respective points in amplitude/time space, because the samples X1 to X5 all represent amplitudes at particular intervals after a starting point when the amplitude was at a known value. The starting point therefore represents a further known point in amplitude/time space. An alternative embodiment might use only the starting point and two subsequent samples.

[0034] Alternative embodiments, for example one which use asynchronous sampling, may be such that the samples do not bear a consistent relationship to a known starting point, and in these embodiments it is desirable for at least three samples to be used.

[0035] Instead of a piezoelectric element, any other form of microphone could be used.

[0036] In the embodiment described above, the mechanical properties of the coin, and particularly its hardness, are tested by examining the results of a coin impact. However, similar techniques could be used for examining the output of a sensor responsive to different characteristics of the coin. For example, an electromagnetic sensor, such as formed by a pair of the coils 18 referred to above, produces a time varying signal as the coin passes it. The signal could for example represent the frequency or the amplitude of the sensor output. (Depending on the nature of the signal, it may not be necessary for analog-to-digital conversion. For example, a counter may be used to measure frequency, in which case the output is already digital.)

[0037] When applying the invention to such sensors, the variations in the signal correspond to variations in the position of the coin, instead of the nature of the vibrations caused by the coin impact. Nevertheless, these variations are characteristic of the coin, and it would therefore be possible to validate the coin using a technique similar to that described above, by analysing samples of the waveform to provide a value indicative of the waveform's shape. Variations in coin speed would cause the shape to expand or contract along the time axis, but this could be dealt with either by sensing coin movement and taking this into account in the processing, or by training the neural network such that speed variations have little effect on the results.

[0038] Although the embodiment described above processes digital samples using a microprocessor, this is not essential. For example, an analog sensor output

could be fed to sequentially-triggered sample and hold circuits, so as to derive a plurality of analog samples which are fed to a hardware neural network.

[0039] The invention has been described in the context of coin validators, but it is to be noted that the term "coin" is employed to mean any coin (whether valid or counterfeit), token, slug, washer, or other metallic object or item, and especially any metallic object or item which could be utilised by an individual in an attempt to operate a coin-operated device or system. A "valid coin" is considered to be an authentic coin, token, or the like, and especially an authentic coin of a monetary system or systems in which or with which a coin-operated device or system is intended to operate and of a denomination which such coin-operated device or system is intended selectively to receive and to treat as an item of value.

Claims

1. A method of validating coins in which a sensor responds to a coin impact by producing a time-varying signal having characteristics dependent on those of the impact, the method including the step of deriving from the signal data representing points in time/amplitude space, and combining the data in a weighted manner to produce an output indicative of coin validity.

2. A method of validating coins in which a sensor responds to a coin impact by producing a time-varying signal having characteristics dependent on those of the impact, the method including the step of deriving from the signal data indicative of three or more points in time/amplitude space, and combining the data to produce an output indicative of coin validity.

3. A method of validating coins in a coin validator including a sensor which produces a time-varying signal in response to an impact of a coin received by the validator, the method comprising the step of sampling the amplitude of the signal at predetermined intervals and combining the sampled data in a predetermined manner to produce an output indicative of the validity of the coin.

4. A method as claimed in claim 3, including the step of determining when the amplitude crosses a predetermined threshold, and commencing a sampling process at that time.

5. A method as claimed in claim 2, 3 or 4, in which the data are combined in a weighted manner.

6. A method as claimed in any preceding claim, including the step of applying a non-linear function to the data.

7. A method as claimed in any preceding claim, including causing the coin to impact an energy-absorbing element in order to produce the coin impact.

8. A method as claimed in any preceding claim, including the step of taking further measurements of the coin in order to determine the validity and denomination of the coin.

9. A method as claimed in claim 8, wherein the further measurements are taken after the coin impact has been produced.

10. A method as claimed in claim 8 or claim 9, wherein said output is also used to determine coin denomination.

11. A method of validating coins in a coin validator including a sensor which produces an output having a waveform representing variations in a sensed parameter in response to the sensing of a coin, the method including the step of deriving data from points on the waveform such that for each point the value of the parameter and the position along the waveform at which the value was established are known, and combining the data in a weighted manner to produce an output indicative of coin validity.

12. A method of validating coins in a coin validator including a sensor which produces an output having a waveform representing variations in a sensed parameter in response to the sensing of a coin, the method including the step of deriving data from at least three points on the waveform such that for each point the value of the parameter and the position along the waveform at which the value was established are known, and combining the data to produce an output indicative of coin validity.

13. A method of validating coins in a coin validator including a sensor which produces an output having a waveform representing variations in a sensed parameter in response to the sensing of a coin, the method including the step of sampling the waveform at predetermined intervals to derive sample data representing points on the waveform such that for each point the value of the parameter and the time at which the value was established are known, and combining the data to produce an output indicative of coin validity.

14. A method as claimed in claim 13, including the step of determining when the amplitude crosses a predetermined threshold, and commencing a sampling process at that time.

15. A method as claimed in claim 12, 13 or 14, in which the data are combined in a weighted manner.

16. A method as claimed in any one of claims 11 to 15, including the step of applying a non-linear function to the data.

17. A method as claimed in claim 1, 5, 11 or 15, or any claim dependent on claim 1, 5, 11 or 15, wherein the weights have been derived by an iterative training process involving the testing of genuine and counterfeit coins, such that the combined data is determined by the shape of the signal and thus is characteristic of the coin.

18. A method as claimed in claim 17, wherein the weights have been derived by an iterative training process using a plurality of reference validators so that common weights can be used for production validators.

19. A coin validator arranged to operate in accordance with a method of any preceding claim.

20. A method of setting up a production coin validator, the method comprising:

(a) deriving, by sensing a coin using a reference validator, an output waveform representing variations in a sensed parameter;
(b) deriving data from points on the waveform such that for each point the value of the parameter and the position along the waveform at which the value was established are known;
(c) combining the data in a weighted manner;
(d) repeating steps (a) to (c) using genuine and counterfeit coins while adjusting the weights;
(e) repeating steps (a) to (d) using one or more further reference validators in order to derive common weights for the reference validators which result in the combined data discriminating between genuine and counterfeit coins; and
(f) storing data representing the weights in the production validator for use in performing validation operations.

21. A method as claimed in claim 20, including the further step of individually calibrating the production validator by using it to sense genuine coins and using the sensor output to derive a suitable acceptance criterion for the combined data.

22. A method of setting up a coin validator, the method comprising the steps of:

(a) sensing a coin using a sensor of the validator and deriving therefrom an output waveform representing variations in a sensed parameter;
(b) deriving data from points on the waveform such that for each point the value of the parameter and the position along the waveform at which the value was established are known;
(c) combining the data in a weighted manner;
(d) repeating steps (a) to (c) using genuine and counterfeit coins, while adjusting the weighting in order to enhance the discrimination between genuine and counterfeit coins; and
(e) storing data representing the weighting in the validator for use in performing validation operations.

23. A method as claimed in claim 20, 21 or 22, wherein the waveform is a time-varying signal produced in response to a coin impact.

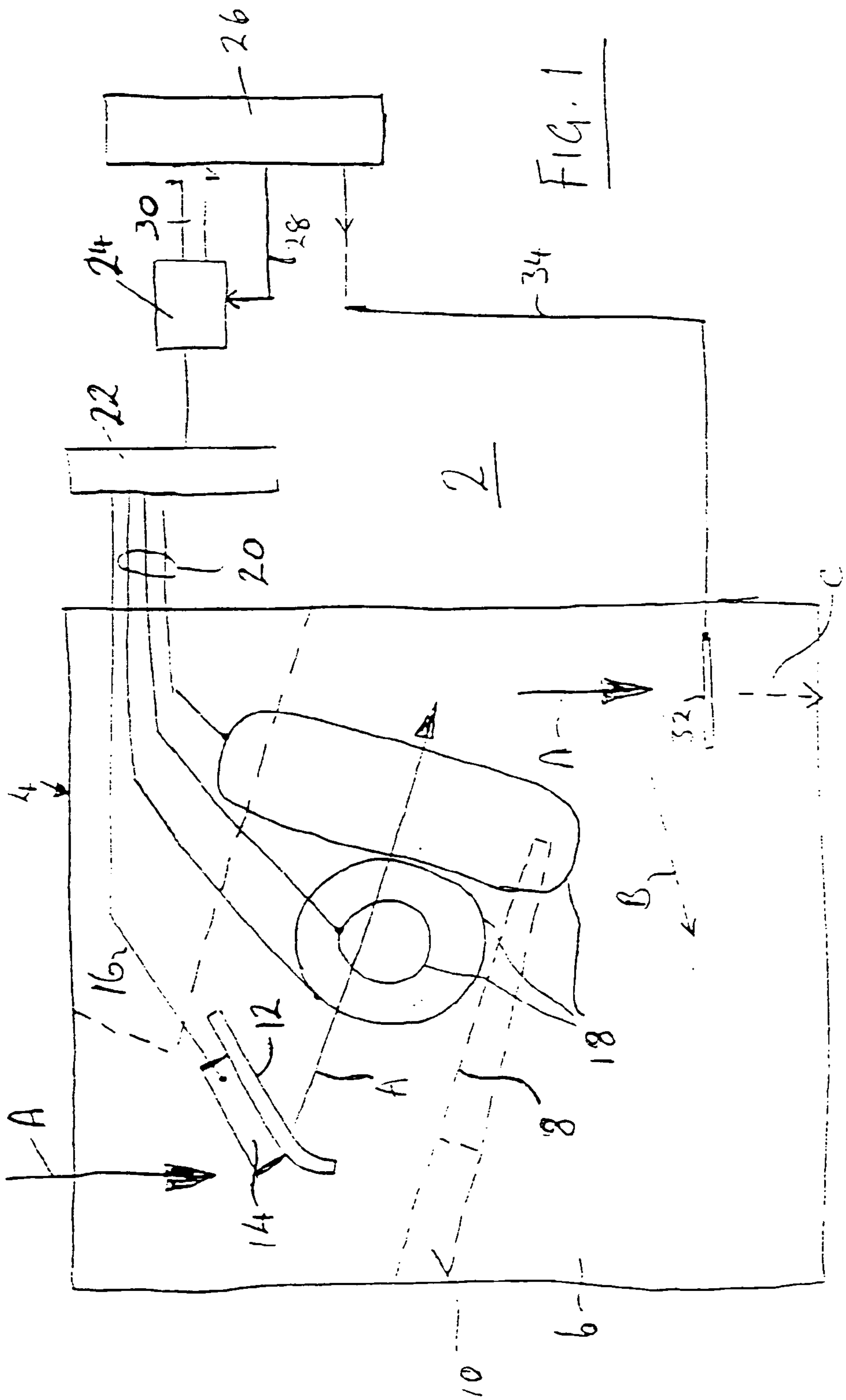

FIG. 1

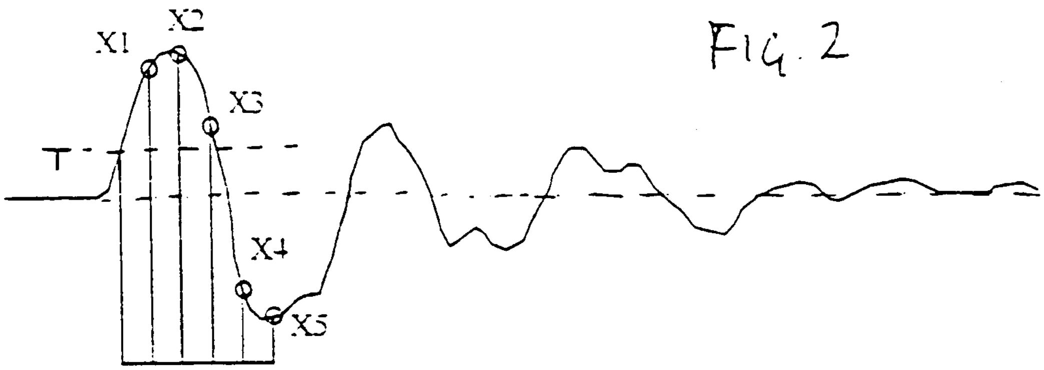

FIG. 2

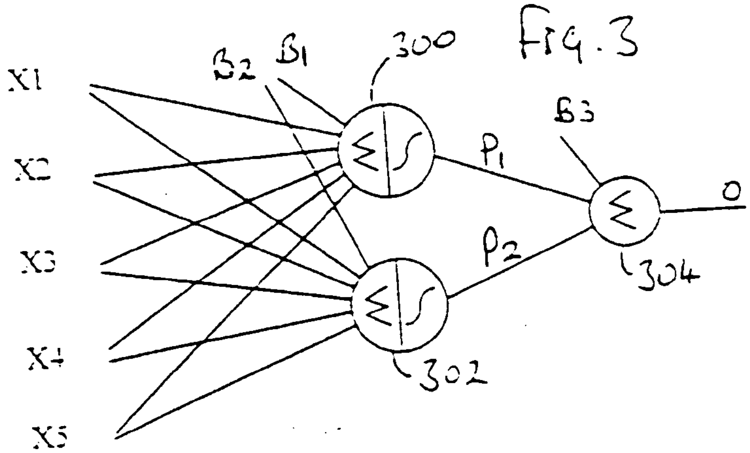

FIG. 3